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PROJECT APOLLO

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SUMMARY

A study was made to determine the magnitude of the errors encountered when the following assumption is made in the RTCC logic for the lunar orbit insertion maneuver. The assumption is that, if the angular momentum vectors for the maximum and minimum acceptable azimuths and for any intermediate azimuth at lunar landing were propagated back to the LOI point, the angular momentum vector for the intermediate azimuth would be in the plane defined by the vectors for the maximum and minimum azimuths. The results of the study show that the errors involved are small enough in magnitude to cause little concern about the accuracy of the RTCC LOI logic.

INTRODUCTION

There will be maximum and minimum acceptable values for the azimuths of the spacecraft state vector during lunar landing. In order to define the plane created by these two azimuth values at LOI, the angular momentum vectors for these values at lunar landing are propagated backward approximately 21 hours to the LOI point where they define the plane. The assumption made in the RTCC logic is that if the angular momentum vector of an intermediate (between the maximum and minimum) azimuth value during landing were propagated backward to the LOI point, it would be contained in the plane defined above. Due to the oblateness of the moon, and the earth and sun gravitational perturbations, etc., errors in both $\Delta\psi_{LOI}$ and β are incurred with this backward propagation. This study was initiated in order to verify that excessive errors would not be caused by this assumption. Obviously this verification is necessary in order to insure the sfaety of the crew as well as the success of the mission.

In setting up the study, a wide range of azimuths over the landing site as well as several landing sites themselves were considered in order to insure a reasonable range of cases would be covered. Several combinations of maximum, minimum, and intermediate azimuths over the landing site were precision integrated backward in time to the approximate LOI point where the errors in $\Delta\psi_{LOI}$ and β were determined. These errors were plotted and are shown in the enclosed figures.

SYMBOLS

LOI	lunar orbit insertion
RTCC	Real-Time Computer Complex
ψ_{LS}	selenographic azimuth over landing site, deg
$\Delta\psi_{LS}$	difference between minimum acceptable azimuth over landing site and intermediate azimuth over same site, deg
$\Delta\psi_{LOI}$	difference between minimum acceptable azimuth over landing site propagated backward to LOI and intermediate azimuth over landing site also propagated backward to LOI, deg
$\Delta\psi_{LOI\ ERROR}$	difference between $\Delta\psi_{LS}$ and $\Delta\psi_{LOI}$, deg
P_{mm}	plane defined by angular momentum vectors of maximum and minimum acceptable azimuths over landing site propagated backward to LOI
β	angle between unit normal of defined plane P_{mm} and the angular momentum vector of an intermediate azimuth over landing site propagated backward to LOI, deg
β_{ERROR}	miss distance of intermediate azimuth angular momentum vector when propagated back to defined plane P_{mm}, deg

ANALYSIS

An initial landing site was arbitrary chosen to be at 0° longitude and 0° latitude. From this site state vectors with maximum and minimum acceptable azimuths of -95.0° and -85.0°, respectively, were chosen. Intermediate azimuth values of -87.0°, -90.0°, and -92.0° were also chosen. Each state vector with the above mentioned azimuth over the landing site was then propagated backward 21 hours (10.5 revolutions) to a point near LOI. At this point the plane created by the maximum and minimum azimuth values (P_{mm}) was defined by crossing their angular momentum vectors to achieve a unit normal to that plane. The angular momentum vectors of the intermediate azimuth state vectors at this point near LOI were then dotted into the unit normal mentioned above to obtain a measure of the error involved with the 21-hours backward propagation. A value of 90.0° for β indicates that the intermediate azimuth would still be contained in the plane P_{mm} at the point near LOI. The error in $\Delta\psi_{LOI}$ was also determined at this point near LOI by dotting the angular momentum vector of the minimum acceptable azimuth into the angular momentum vector of the intermediate azimuth. By subtracting the value of $\Delta\psi_{LS}$ from the corresponding value of $\Delta\psi_{LOI}$, a direct measure of the error involved with this parameter is obtained. This same procedure for determining errors in β and $\Delta\psi_{LOI}$ was followed using other combinations of azimuth and landing sites as shown in table I.

The integrating trajectory program ARM05 was used to propagate the state vectors backward from the landing sites to the point near LOI. This program considered nearly all of the expected perturbations acting on a spacecraft in lunar orbit, even though the only significant perturbations proved to be the moon's zonal and sectorial harmonic coefficients (J2 and J22).

RESULTS

Figure 1 shows the errors in β for a landing site latitude of 0.0°. It is readily apparent from the figure that as the angle between the maximum and minimum acceptable azimuths increases, the error induced in β also increases. Another fact obtained from the figure is that as the acceptable azimuth range moves away from the -90.0° value the errors in β tend to become larger. This is because of a symmetrical effect that this -90.0° value has upon the errors in β.

Figures 2 and 3 show the errors in β for landing site latitudes of 5.0° and -5.0°, respectively. These figures are quite similar to figure 1 with the exception that the symmetrical effect about the -90.0° azimuth value has experienced a slight shift due to the difference in landing site latitudes.

Figure 4 shows the errors in $\Delta\psi_{LOI}$ for the three landing site latitudes of 0.0°, 5.0°, and -5.0°. In this figure it is quickly noted that the errors in $\Delta\psi_{LOI}$ are almost directly porportional to $\Delta\psi_{LS}$ for all three landing site latitudes. This proportion of $\Delta\psi_{LOI}$ error to $\Delta\psi_{LS}$ averages out to approximately 0.375 percent for the three landing site latitudes considered.

CONCLUSIONS

It may be concluded from the results of this study that the errors incurred when using the RTCC LOI logic are insignificant. The maximum errors that can reasonally be expected are 0.1° in $\Delta\psi_{LOI}$ and 0.004° in β. This 0.004° error in β may also be thought of interchangeably as the maximum expected miss distance of the landing site when using the RTCC LOI logic.

TABLE I.- ERRORS INCURRED IN β AND $\Delta\psi_{LOI}$

(a) Landing site latitude = 0.0°

ψ_{LS}, deg	β, deg	β_{ERROR}, deg	$\Delta\psi_{LOI}$, deg	$\Delta\psi_{LOI}$ ERROR, deg	Minimum ψ_{LS}, deg	Maximum ψ_{LS}, deg
-77.0	89.998821	-.001179	2.0074620	.0074620		
-80.0	89.998318	-.001682	5.0187341	.0187341	-75.0	-85.0
-83.0	89.999027	-.000973	8.0300961	.0300961		
-87.0	89.999888	-.000112	2.0076326	.0076326		
-90.0	89.999999	-.000000	5.0190903	.0190903	-85.0	-95.0
-92.0	90.000093	.000093	7.0267332	.0267332		
-97.0	90.000970	.000970	2.0075960	.0075960		
-100.0	90.001676	.001676	5.0189781	.0189781	-95.0	-105.0
-103.0	90.001175	.001175	8.0302550	.0302550		
-77.0	89.998365	-.001635	2.0074620	.0074620		
-80.0	89.997179	-.002821	5.0187341	.0187341		
-83.0	89.997207	-.002793	8.0300961	.0300961		
-85.0	89.997728	-.002272	10.037701	.037701		
-87.0	89.998523	-.001477	12.045331	.045331		
-90.0	89.999994	-.000006	15.056792	.056792	-75.0	-105.0
-92.0	90.000998	.000998	17.064433	.064433		
-95.0	90.002262	.002262	20.075879	.075879		
-97.0	90.002783	.002783	22.083490	.083490		
-100.0	90.002814	.002814	25.094855	.094855		
-103.0	90.001629	.001629	28.106135	.106135		

TABLE I.- ERRORS INCURRED IN β AND $\Delta\psi_{LOI}$ - Continued

(b) Landing site latitude = 5.0°

ψ_{LS}, deg	β, deg	β_{ERROR}, deg	$\Delta\psi_{LOI}$, deg	$\Delta\psi_{LOI}$ ERROR, deg	Minimum ψ_{LS}, deg	Maximum ψ_{LS}, deg
-77.0	89.998808	-.001192	2.0064259	.0064259		
-80.0	89.998294	-.001706	5.0164352	.0164352	-75.0	-85.0
-83.0	89.999009	-.000991	8.0268440	.0268440		
-87.0	89.999858	-.000142	2.0073036	.0073036		
-90.0	89.999949	-.000051	5.0185681	.0185681	-85.0	-95.0
-92.0	90.000052	.000052	7.0262550	.0262550		
-97.0	90.000927	.000927	2.0079982	.0079982		
-100.0	90.001611	.001611	5.0202612	.0202612	-95.0	-105.0
-103.0	90.001132	.001132	8.0327208	.0327208		
-77.0	89.998278	-.001722	2.0064259	.0064259		
-80.0	89.996973	-.003027	5.0164352	.0164352		
-83.0	89.996900	-.003100	8.0268440	.0268440		
-85.0	89.997367	-.002633	10.033997	.033997		
-87.0	89.998121	-.001879	12.041306	.041306		
-90.0	89.999557	-.000443	15.052567	.052567	-75.0	-105.0
-92.0	90.000556	.000556	17.060253	.060253		
-95.0	90.001847	.001847	20.072038	.072038		
-97.0	90.002409	.002409	22.080049	.080049		
-100.0	90.002538	.002538	25.092289	.092289		
-103.0	90.001503	.001503	28.104758	.104758		

TABLE I.- ERRORS INCURRED IN β AND $\Delta\psi_{LOI}$ - Concluded

(c) Landing site latitude = -5.0°

ψ_{LS}, deg	β, deg	β_{ERROR}, deg	$\Delta\psi_{LOI}$, deg	$\Delta\psi_{LOI\ ERROR}$, deg	Minimum ψ_{LS}, deg	Maximum ψ_{LS}, deg
-77.0	89.998865	-.001135	2.0083880	.0083880		
-80.0	89.998384	-.001616	5.0208905	.0208905	-75.0	-85.0
-83.0	89.999068	-.000932	8.0331209	.0331209		
-87.0	89.999921	-.000079	2.0078763	.0078763		
-90.0	90.000045	.000045	5.0194708	.0194708	-85.0	-95.0
-92.0	90.000133	.000133	7.0270123	.0270123		
-97.0	90.000987	.000987	2.0071573	.0071573		
-100.0	90.001702	.001702	5.0175530	.0175530	-95.0	-105.0
-103.0	90.001188	.001188	8.0275717	.0275717		
-77.0	89.998492	-.001508	2.0083880	.0083880		
-80.0	89.997452	-.002548	5.0208905	.0208905		
-83.0	89.997582	-.002418	8.0331209	.0331209		
-85.0	89.998144	-.001856	10.041131	.041131		
-87.0	89.998961	-.001039	12.049018	.049018		
-90.0	90.000433	.000433	15.060603	.060603	-75.0	-105.0
-92.0	90.001417	.001417	17.068145	.068145		
-95.0	90.002624	.002624	20.079173	.079173		
-97.0	90.003090	.003090	22.086332	.086332		
-100.0	90.003020	.003020	25.096741	.096741		
-103.0	90.001716	.001716	28.106751	.106751		

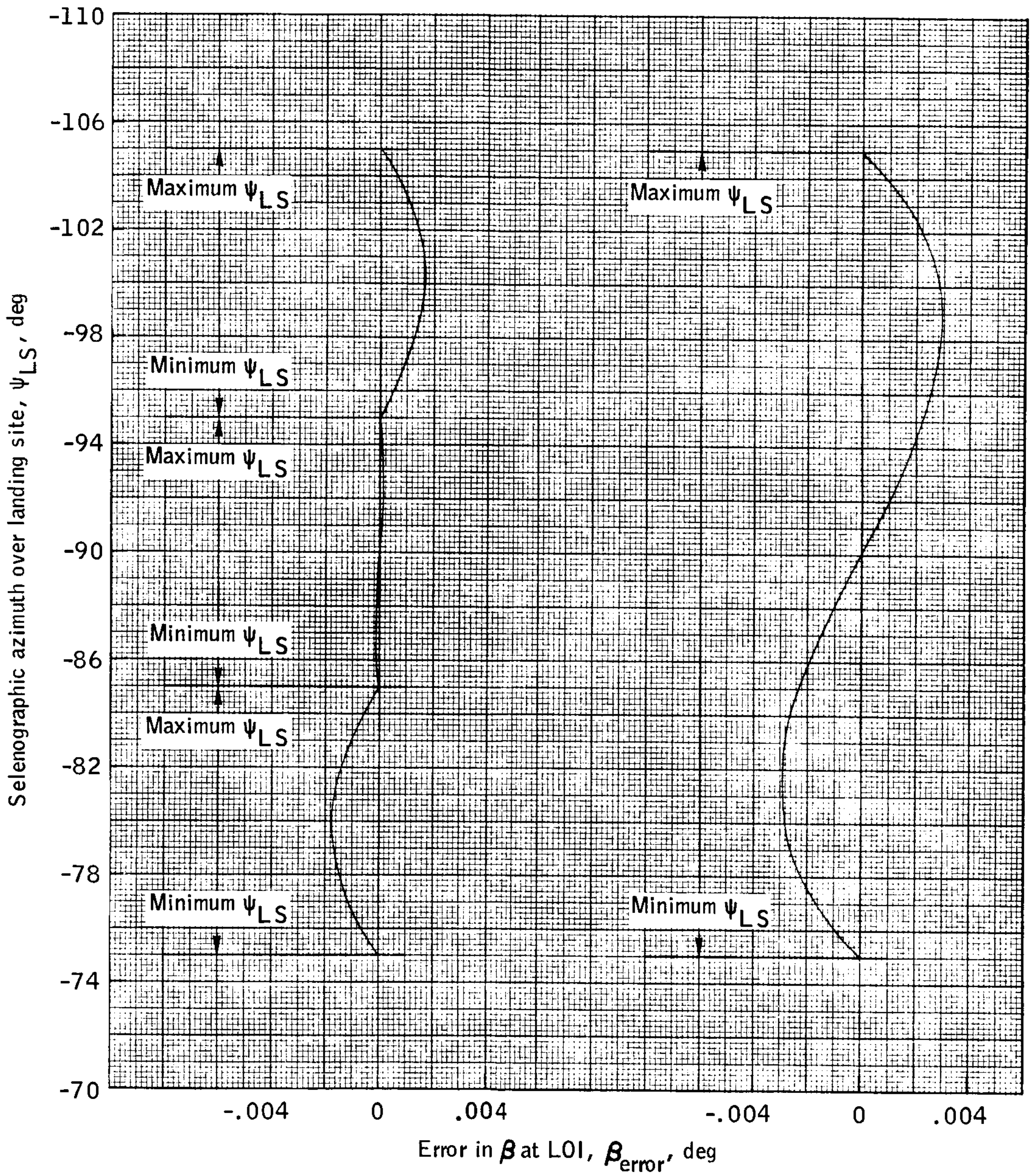

Figure 1.- Errors in β at LOI for 0.0° landing site latitude.

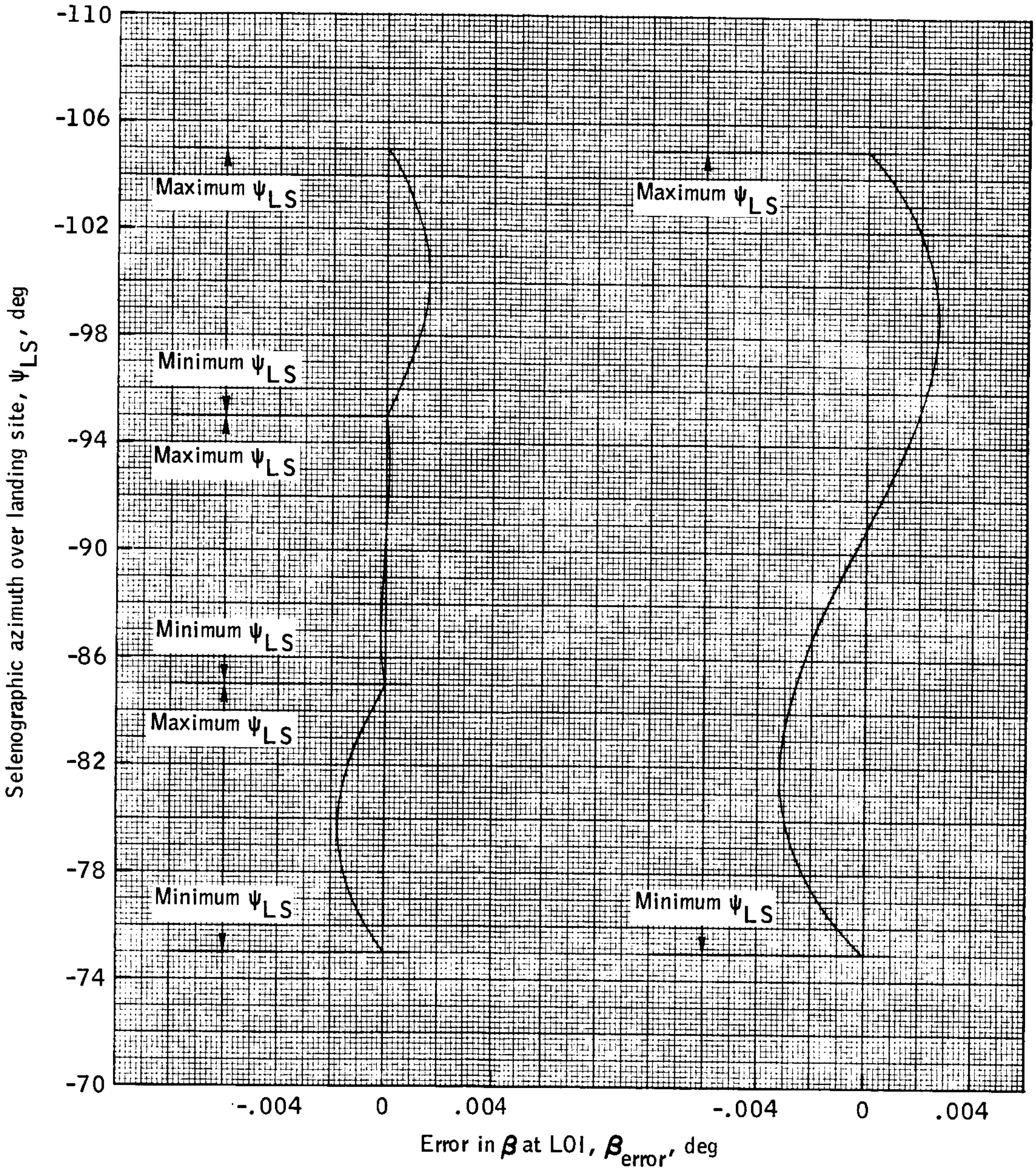

Figure 2.- Errors in β at LOI for 5.0° landing site latitude.

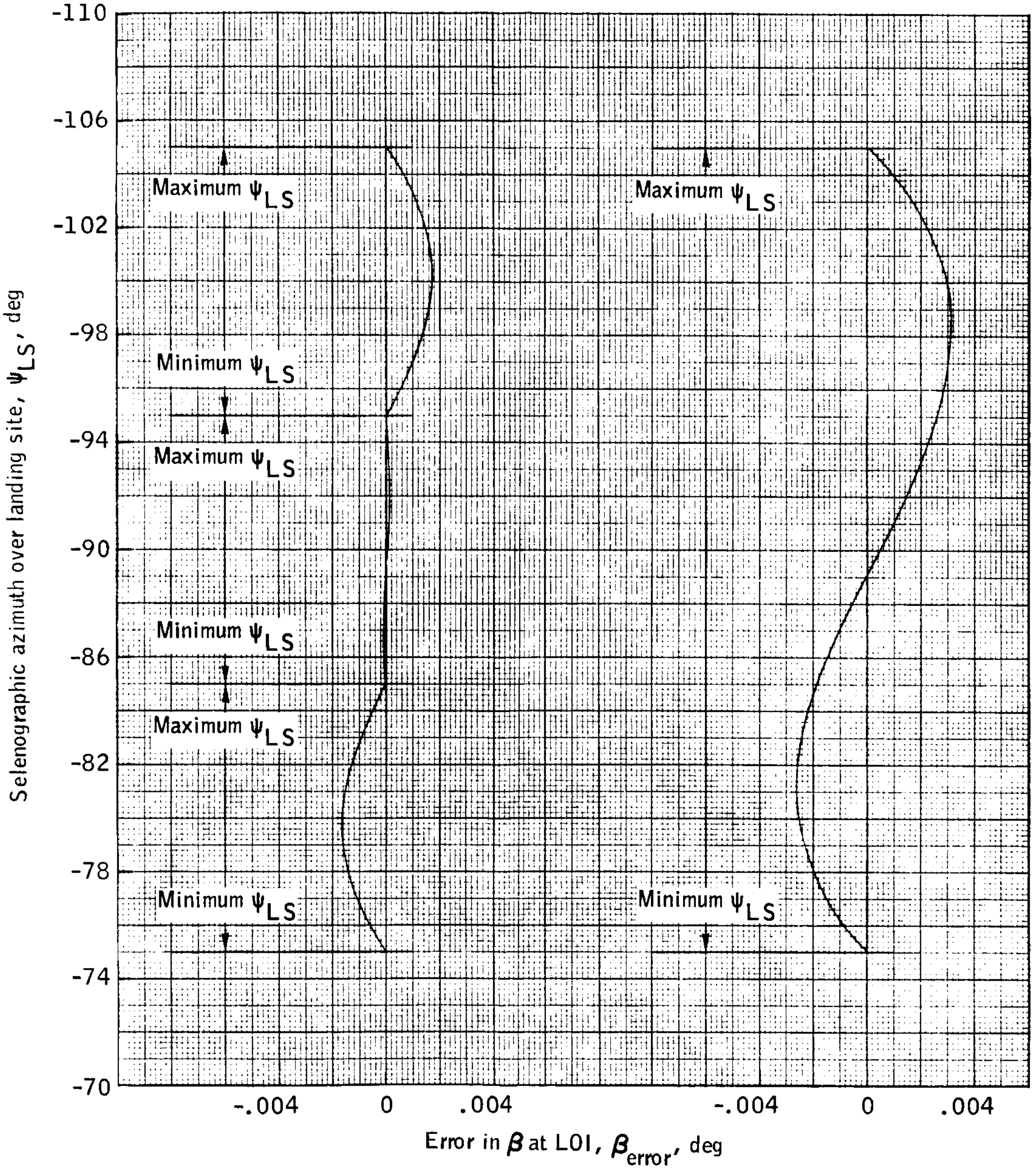

Figure 3.- Errors in β at LOI for -5.0° landing site latitude.

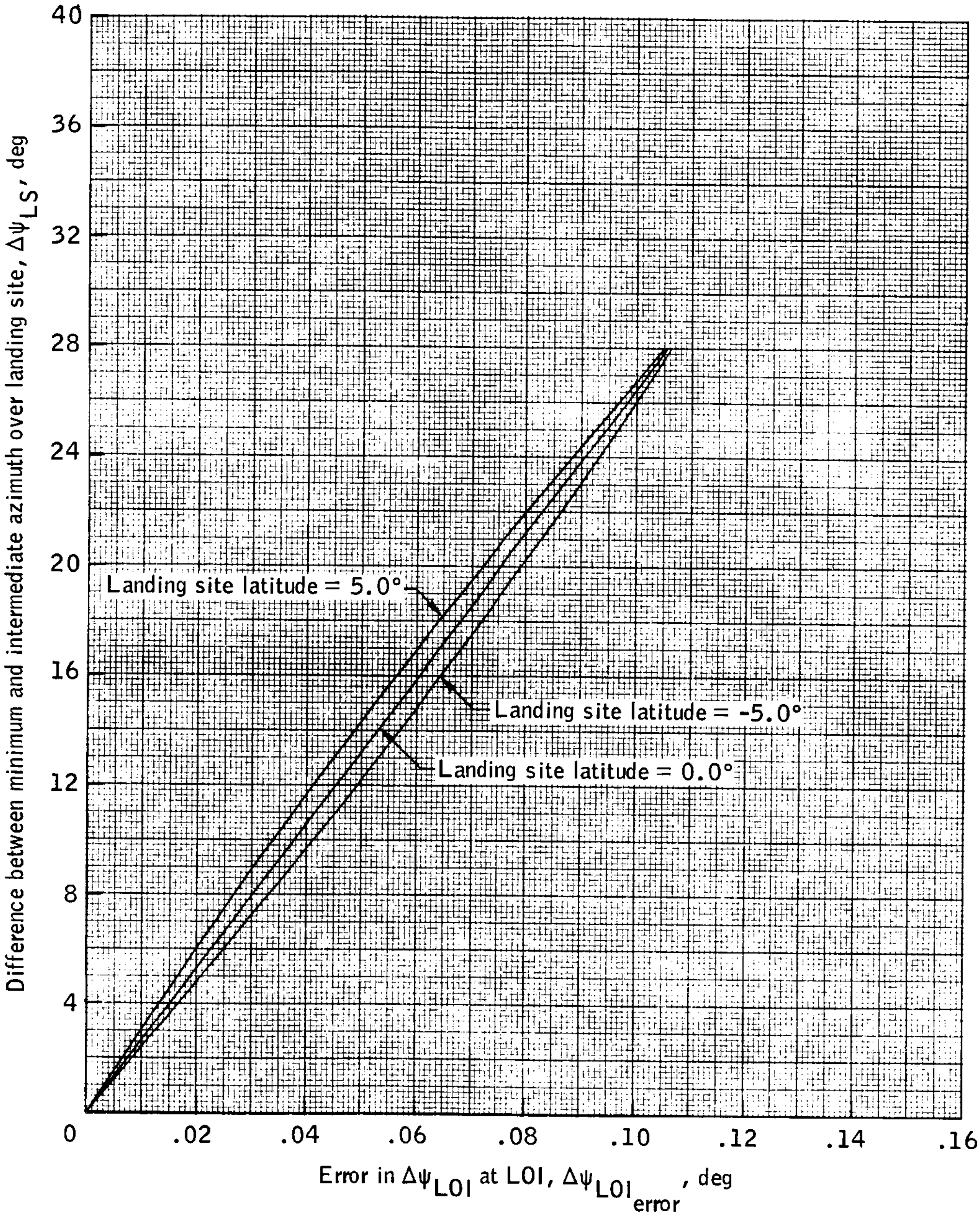

Figure 4. Errors in $\Delta\psi_{LOI}$ at LOI for landing site latitudes of 0.0°, 5.0°, and -5.0°.

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1. Wiley, Robert F.: RTCC Requirements for Mission G: LOI Targeting Processor. MSC IN 68-FM-34, February 1, 1968.